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Design of Roll Control System for Rockets by Simulation Techniques†

N. V. KADAM*, S. DASGUPTA*, KUSUM CHANDRAGUPTA* & N. SUNDARARAJAN*

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This paper describes the application of simulation techniques both analog and digital to arrive at optimum control system parameters namely control thrust level, attitude and rate feedback gains for roll control of a sounding rocket.

DURING an uncontrolled flight of a rocket through the atmosphere, an angular motion about its longitudinal axis (rolling motion) is developed due to aerodynamic disturbance torques arising out of fin-misalignment, thrust misalignment etc. In order to effect attitude control about the pitch and yaw axes of rockets during flight through the atmosphere, it becomes necessary to reduce this rolling motion to zero. The maintaining of roll attitude as small as possible calls for an active control system.

This study describes the fixation of parameters for such a control system, by means of analog and digital simulation[1,2]. Though the design by simulation can be done for any rocket, it is illustrated here for a roll control system of a Rohini-125 sounding rocket. A preliminary estimation of parameters for roll control system for Rohini-300, assuming time invariant plant and constant disturbances has been given in (Tech. memorandum).

SYSTEM DESCRIPTION

The system is illustrated in the block diagram form in Fig. 1. The control law selected is of the 'Single level bang-bang control with dead zone' type. The activating function is obtained by using a combination of quantities proportional to roll angle and roll rate.

The system dynamics about the roll axis is given by

$$\frac{d}{dt}\left[I(t)\,\dot{\theta}(t)\right] + A_d(t) = A(t) - u(t-t_d) \qquad (1)$$

where $I(t)$ — roll moment of inertia at time t

$\theta(t)$, $\dot{\theta}(t)$ — the roll angle and roll rate respectively.

$A_d(t)$ — Aerodynamic damping torque

$A_d(t) = K_d(t)\dot{\theta}$ where $K_d(t)$ is the aerodynamic damping coefficient.

$A(t)$— Aerodynamic roll inducing torque

$u(t)$ — Control torque at t

t_d — Control actuation delay time

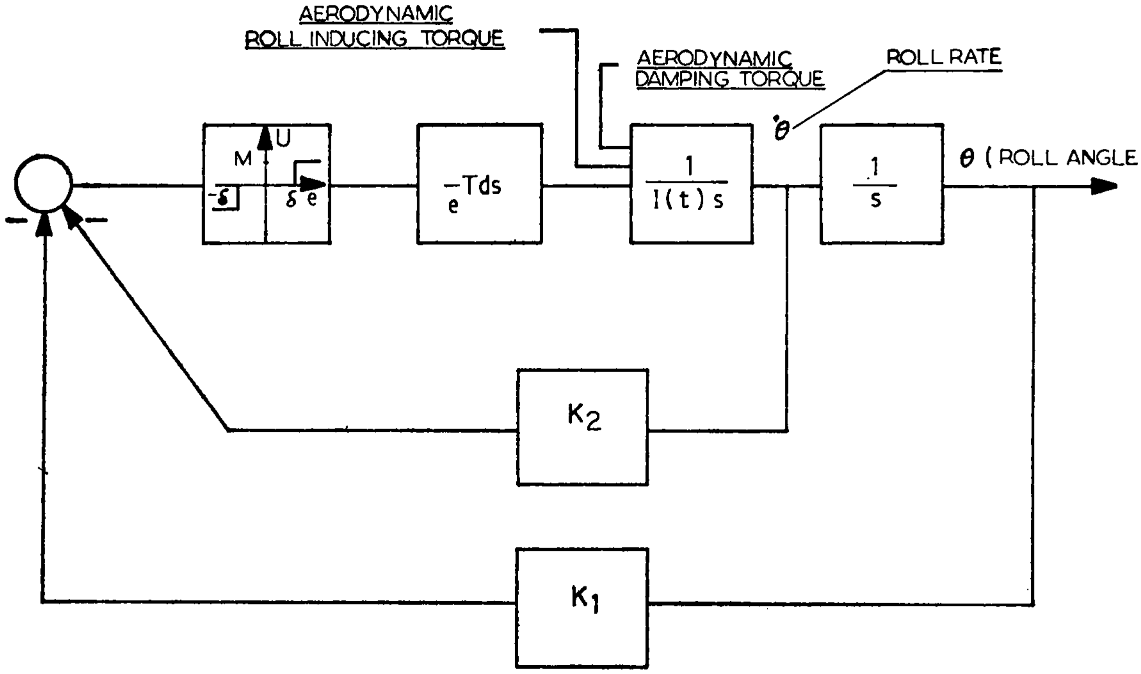

Fig. 1. Block diagram

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$I(t)$ is assumed to be

$$I(t) = I(t_0) - t \cdot \left[\frac{I(t_0) - I(t_b)}{t_b}\right] \quad \text{for } t \leqslant t_b \qquad (2)$$
$$= I(t_b) \text{ for } t > t_b$$

where t_0, t_b are the initial and burn out times respectively. The linear variation of moment of inertia is true only for end-burning type of propulsion. For radial type of burning appropriate expression for $I(t)$ may be used.

Equation (1) can be written as

$$I(t)\,\ddot{\theta}(t) + [\dot{I}(t) + K_d]\,\dot{\theta}(t) = A(t) - u(t - t_d) \qquad (3)$$

from (2), $\dot{I}(t) = -\left[\frac{I(t_0) - I(t_b)}{t_b}\right]$

for the RH-125 roll control system $[K_b + \dot{I}(t)]$ is found to be very small and hence has been neglected in the simulation.

The error function is given by

$$e = (K_1\theta + K_2\dot{\theta})$$

The control logic is given by

$$u(t) = \left.\begin{array}{l} M \text{ for } e > \delta \\ = -M \text{ for } e < -\delta \\ = 0 \text{ for } |e| \leqslant \delta \end{array}\right| \; t \geqslant t_d$$
$$= 0 \text{ for } t < t_d$$

where δ — dead zone on the error function.
M — control torque level.

The aim of this study is to arrive at 'optimum' values of the set of parameters K_1, K_2 and M. By 'optimum' is meant the maintenance of θ within certain limits demanded by the accuracy requirements with less fuel consumption. The simulation methods are presented here to achieve the same.

The best design, in this case would be a system with a rate feedback corresponding to the critical damping and control torque level and dead-zone of such magnitudes that the control torque acts in only one direction (opposing the aerodynamic torque) throughout the flight time. This avoids unnecessary fuel expenditure.

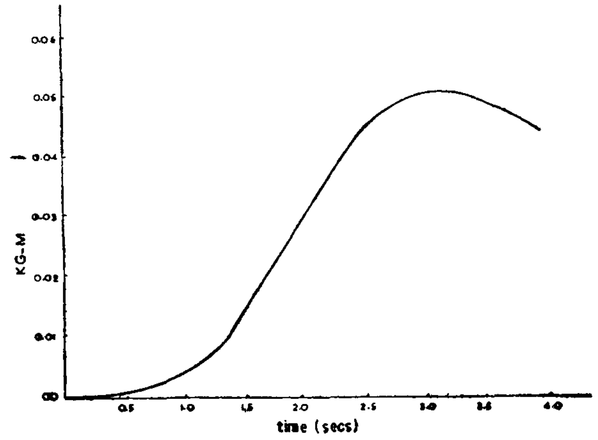


Fig. 2. Aerodynamic roll inducing torque

ANALOG SIMULATION

The design of roll control system satisfying the above criteria is carried out by simulation methods which are illustrated here for Rohini-125 rocket. The analog simulation discussed here incorporates time-varying moment of inertia and the aerodynamic roll torque in Fig. 2[3] (approximated as a linear function) but it does not include the control delay time. The controlled flight time is taken to be 3.6 sec.

Amplitude Scaling

Following maximum values are used for amplitude scaling of the various quantities :

$\theta_m = 0.10$ rad.
$\dot{\theta}_m = 0.16$ rad/sec.
$M_m = 0.1$ kgm.
Range of K_1 and $K_2 = 0$ to 1.0.

The values of θ_m and $\dot{\theta}_m$ have been estimated from flight test and practical considerations. The maximum error corresponding to $K_1 = 1.0$ $K_2 = 1.0$ is $E_m = 0.26$ rad.

Time Scaling

Time scaling has been done so as to slow down the problem by a factor 5 i.e.

$T = 5t$ where T — Computer time
t — Problem time

Results of Analog Simulation

The simulation has been used to study the effect of the following control parameters on the roll angle :

(1) Control law gains K_1, K_2

(2) Control torque level M

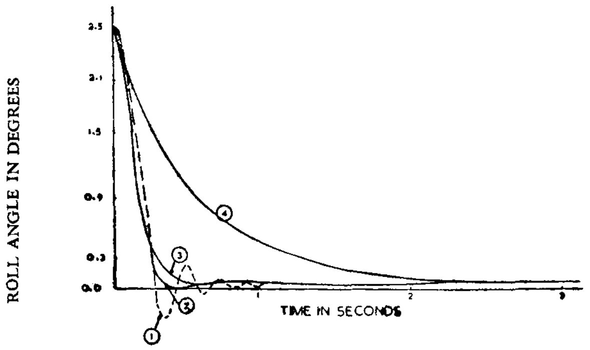
The following observations are in order :

(1) Effect of changing K_1 for given values of K_2 and δ. Let K_1 be changed by a factor n. The equations of the dead-zone boundaries will then become

$$nK_1\theta + K_2\dot{\theta} = \pm\,\delta$$

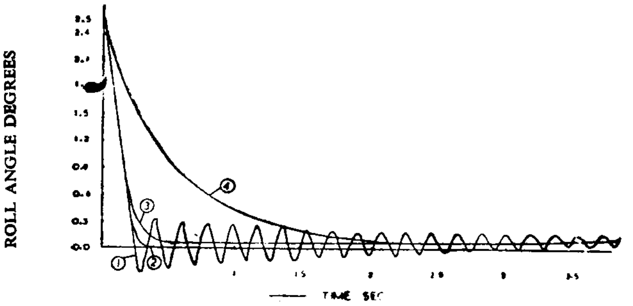
Dividing both sides by n,

$$K_1\theta + \frac{K_2\dot{\theta}}{n} = \pm\,\delta/n.$$



Control torque = 0.6 kgm
$K_1 = 1.0$; (1) $K_2 = 0.01$, (2) $K_2 = 0.05$, (3) $K_2 = 0.1$, (4) $K_2 = 0.5$

Fig. 3A. Analog simulation results



M=0.1 kgm
$K_1=1.0$, $K_2=0.01$, $K_2=0.05$, $K_2=0.1$, $K_2=0.5$

Fig. 3 B. Analog simulation results

Hence, the effect of changing K_1 by a factor n for a fixed value of K_2 and δ will be the same as the effect of changing K_2 and δ by a factor $1/n$ for the same value of K_1.

If both the K_1 and K_2 are changed by a factor n, the effect will be same as the effect of keeping the K_1 and K_2 unchanged but changing δ by a factor $1/n$.

(2) The roll angle vs time curves are given in Fig. 3 for different values of control parameters. The curves in Fig. 3 show the effect of various damping constant $K = (K_2/K_1)$ on the system for different torque levels. The value of $K = 0.05$ damps the system critically and the roll angle θ is within the dead-zone in the smallest time.

(3) The control torque level of $M = 0.5\ M_m$ where M_m is the max. torque level of 0.1 kgm, is adequate to control the roll angle throughout the burning time of 3.6 sec. The aerodynamic roll inducing torque characteristic in Fig. 2 shows that the disturbance torque reaches its maximum value of 0.05 kgm at 3.51 sec., falling sharply thereafter. Hence the control torque of 0.05 kgm is adequate to control the roll angle throughout the flight.

Based on the above study the following values of control parameters are arrived at :

$\delta = 0.05°$ $\quad M = 0.05$ kgm.
$K_1 = 1.0$ $\quad K_2 = 0.05$

DIGITAL SIMULATION

The digital simulation programme incorporates time varying moment of inertia, aerodynamic roll inducing torque as in Fig. 2 and control actuation delay times. Simulation is done for a flight time of 3.9 sec.

For the reason given in section 3, variations of K_2, δ and M are studied for a fixed value of $K_1 = 1.0$.

DISCUSSION OF RESULTS

Effect of changing K_2 for given value of K_1 and δ

Fig. 4 shows the plot of $|\theta|$ max. $|\dot{\theta}|$ max and ($T_{0n} \times M$) observed during the controlled flight time of 3.9 secs versus K_2. Though the graphs in Fig. 4 are given for $\delta = 0.4°$ and $M = 0.07$ kgm, studies were conducted for different values of δ and M and it was observed that the nature of the graph was similar.

It is seen from Fig. 4 that the values of K_2 within the range 0.04 to 0.075 are satisfactory from minimum of maximum roll angle deviation, minimum of maximum roll rate and minimum control impulse point of views. $K_2 = 0.05$ was selected for studying the effect of variation of δ and M.

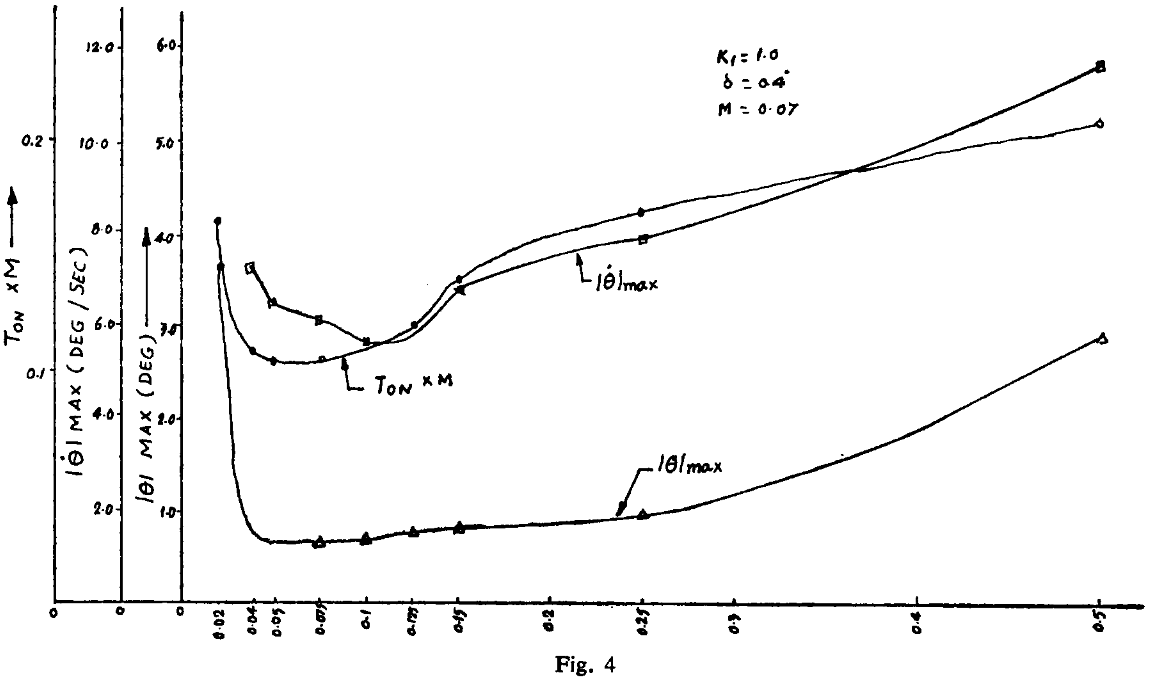


Fig. 4

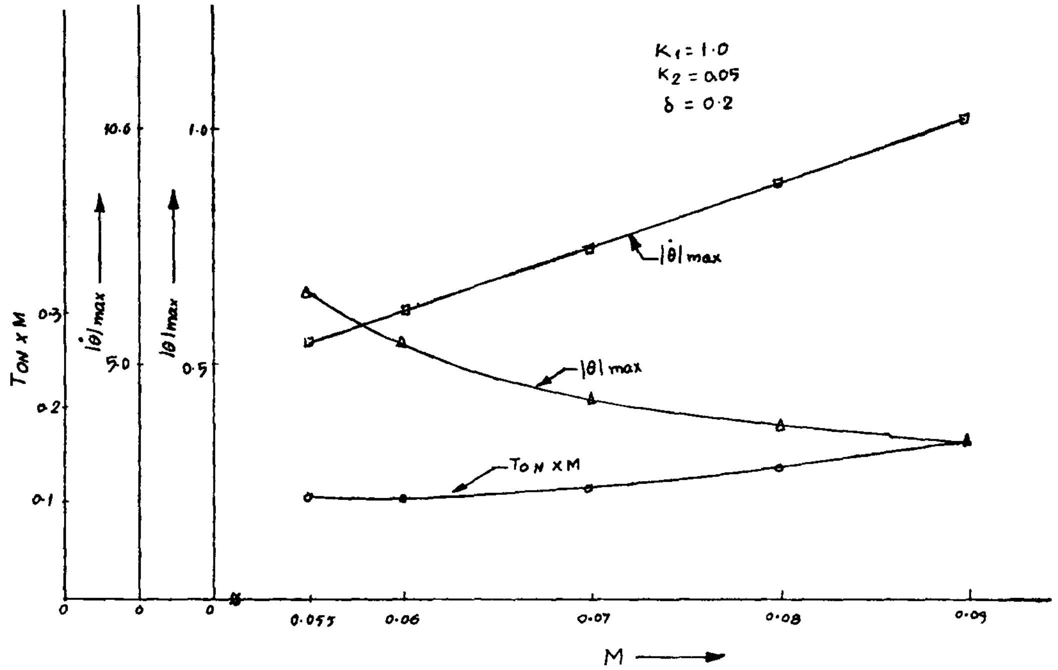


Fig. 5

Effect of changing δ and M for given values of K_1 and K_2

After fixing the value of K_2, various combinations of δ and M were studied, the results of which are not given here for brevity. It is observed that for a particular value of M the accuracy improves (i.e. $|\theta|$ max decreases) for decreasing value of δ upto a certain value and again deteriorates for further decrease in the value of δ. It is also observed that the control torque-impulse ($T_{0n} \times M$) for a given value of M increases continuously for decreasing value of δ. By making a trade-off between accuracy and control impulse δ was selected as 0.2° and from Fig. 5, M was fixed as 0.07 kgm. Thus the control system parameters are as follows :

$K_1 = 1.0 \qquad K_2 = 0.05$
$\delta = 0.2° \qquad M = 0.07$ kgm

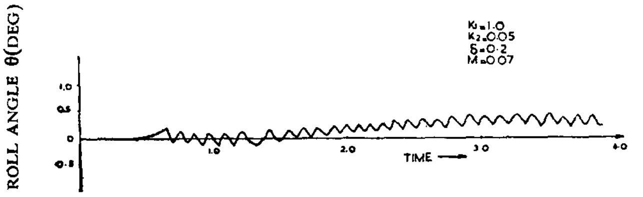


Fig. 6A. Roll angle vs time

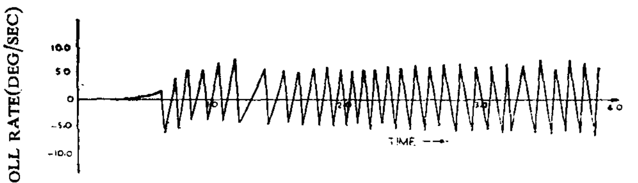


Fig. 6 B. Roll rate vs time

With these values, the roll history of the system is shown in Fig. 6.

REMARKS

Analog simulation was carried out on the AC-20 Analog Computer (ECIL). The accuracy of observations is 0.1% of full scale. Again due to the finite operational amplifier gain, the switching circuit does not conform to an exact relay type nonlinearity, but has a finite slope. The time delay in control actuation has been neglected in the analohg simulation. The criterion for parameter variation in the analog simulation has been to obtain a critically damped system response. In the digital simulation (IBM 360/44 system, SSTC), however, the criterion for parameter selection is based on fuel optimality in addition to the nature of response. As such the design values obtained from the digital simulation are more accurate and hence recommended.

CONCLUSIONS

The usefulness of simulation techniques in arriving at the design parameters for a control system have been illustrated here. Even though the techniques are illustrated for roll control of RH-125, they are general in nature and can be applied to any other control system.

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REFERENCES

1. KORN (G A) and KORN (T M). Electronic Analog and Hybrid Computers' Mc-Graw Hill Co., N. Y., 1964.
2. CHU (Y). Digital Simulation of Control Systems' Mc-Graw Hill Co., N.Y., 1969.
3. Technical Memorandum ARD Division, VSSC. Roll Control of TVC RH-125 EXT/TM/S/PS/CO/3/72
4. SUDHAKARA RAO (K) and BHAT (K P M). TVC Project—Control System Specification for Roll Control for RH-300 SSTC/CGI/TM/05/72.